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EFFECTS OF MULTIPLE SHOT PEENING/CADMIUM PLATING ON HIGH STRENGTH STEEL

METCUT RESEARCH ASSOCIATES INC.
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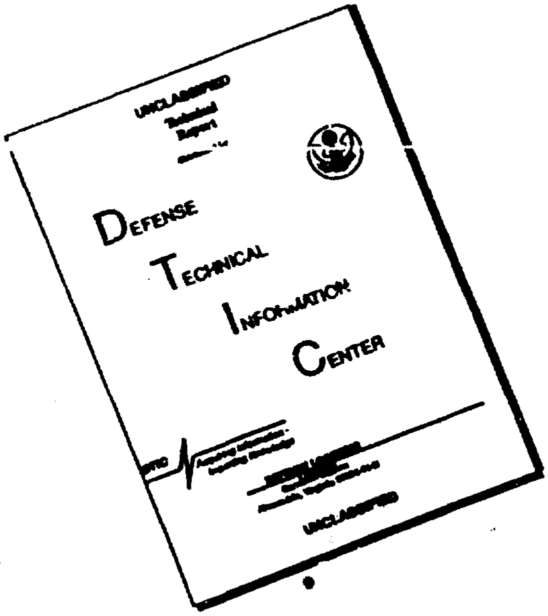

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This report covers the effect of multiple shot peening and cadmium plating operations on a high strength steel alloy used in landing gear applications. The basis for determining this effect was fatigue and stress corrosion tests in a high humidity environment.

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FOREWORD

This final technical report covers all work performed under Contract F33615-78-C-5201 entitled "Effect of Multiple Shot Peening/Cadmium Plating on High Strength Steel." This project was accomplished under the technical direction of Mr. A. Gunderson of the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The effort was performed during the period from 15 September 1978 to 15 December 1979 and was released by the authors in February 1980.

The program deals with the effect of multiple shot peening in cadmium plating operations on a high strength steel alloy used in landing gear applications. The basis for determining this effect were fatigue tests and stress corrosion tests in a high humidity environment.

The subject contract was placed with Metcut Research Associates Inc. of Cincinnati, Ohio and Metcut chose as its principal sub-contractors the Metal Improvement Company of Cincinnati, Ohio and Hohman Plating Company of Dayton, Ohio. Metcut provided the overall direction of the program as well as the facilities for manufacturing the test specimens and performing the fatigue tests. Metal Improvement Company performed the shot peening operation for each of the cycles during the program. The Hohman Plating Company did both the cadmium plating by vapor deposition and also the stripping required between each successive plate cycle.

At Metcut, the program was under the supervision of John B. Kohls, William J. Stross, Dr. John T. Cammett III and L. R. Gatto. Activities at the Metal Improvement Company were under the direction of Bob Gillespie and at the Hohman Company under the direction of Dick Gordman.

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INTRODUCTION

High strength steel is widely used in the structural members of aircraft landing gear. Typically, these components are finished by shot peening plus cadmium and chromium plating followed by a paint system in order to enhance both fatigue and corrosion resistance. Periodic overhaul of such components usually includes reworking or repeating of these surface treatments. A typical rework cycle consists of stripping the components to the bare steel, inspecting for discontinuities, building up and remachining the worn areas, and then the finishing sequence.

During the total useful life of the aircraft, the landing gear is subjected to several of these rework cycles. It is important in a program of this variety to insure proper manufacturing techniques of the test specimens. The test specimens used on this program were low stress ground to insure no grinding burn existed on the specimen surface. After manufacturing, several specimens were checked with a nital etch procedure to verify that the surface conditions was indeed free of grinding burn.

The purpose of this program is to establish the effects of the original and the rework peening/plating cycles on fatigue and stress corrosion as being either adverse or beneficial. The program schedule as specified by Materials Laboratory personnel is given in Figure 1. This schedule calls out metallurgy, tensile, fatigue and stress corrosion as the evaluation techniques.

Metallography work compares the hardness level and depth of affected zone induced by shot peening as a function of the intensity of peening and the number of rework peening cycles. Particular attention is paid to the possible presence of untempered martensite in both the original and the redundantly peened surfaces. Incidents of micro cracking is also evaluated. Fatigue and stress corrosion testing has served as the principal basis for evaluating the effect of both the original and the repeated surface treatments. Stress ratios of R = +0.1 and -0.3 were used on these fatigue tests. Tensile tests were run to identify the basic material characteristics. All tests were conducted at room temperature.

Evaluation/Test	Baseline	SHOTPEENING/CADMIUM PLATE Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
1. Metallurgical						
a. Standard Intensity	3	3	3	3	3	3
b. High Intensity		2	2	2	2	2
2. Tensile	3	3	3	3	3	3
3. Fatigue						
a. R = 0.1 High Stress	6	4	2	2	2	2
Med. Stress	6	2		2		2
b. R = -0.3 High Stress	6	4	2	2	2	2
Med. Stress	6	2		2		2
c. Interrupted R = 0.1 ¼ life between each peen/plate cycles		3 →	→	→	→	→
		3 →	→	→	→	→
4. Stress Corrosion						
a. Smooth	4	2	2	2	2	2
b. Precracked	2	2	1	2	1	2

Figure 1 - Preliminary Program Summary

SECTION II

OBJECT OF PROGRAM

The object of this program was to determine if multiple shot peening and plating operations have an adverse or beneficial effect on the service life of a high strength steel landing gear. These multiple peening and plating operations are the type that would occur during periodic, consecutive overhauls necessary in the maintenance of various aircraft components.

SECTION III

SCOPE OF PROGRAM

The scope of this program was to determine on a laboratory basis the effect of multiple shot peening and cadmium plating operations on high strength steel alloys used in landing gear application. The material selected for this program was vacuum melted 4340 steel alloy meeting the requirements of MIL-S-8844, heat treated to the 260-280 ksi (1790-1930 MPa) ultimate strength level. This material is used in landing gear of many earlier aircraft which have been subjected to multiple shot peening/chromium and cadmium plating cycles. The material tested was 3/8" (9.6 mm) thick plate with a minimum of .100 in. (2.54 mm) of material removed from the forged surfaces. The procedures followed in the surface treatment of the test coupons were as follows:

1. Shot peening of metal parts per MIL-S-13165B.
2. Cadmium plating per MIL-C-8837, Type II.

The basis for determining a beneficial/detrimental effect included metallography, tensile evaluation, fatigue testing, and stress corrosion studies. The metallography portion was carried out at two peening intensity levels, .008 to .012A (.2 to .3 mm A) and also .012 to .016A (.3 to .4 mm A). Tensile testing was performed per ASTM Test Method E8. The fatigue test was in accordance with ASTM E-466 at R ratios of +0.1 and -0.3. To evaluate the effect of fatigue loadings in between peening/plating cycles, an interrupted test series was conducted as program element 3.c. The average life for the one cycle high stress specimens in program elements 3.a and 3.b were divided by four and this number of cycles was applied after each peen/plate cycle.

The stress corrosion testing followed the procedure called out in ASTM E-519 and had a test duration of 200 hours. All fatigue and stress corrosion testing was performed in a test environment of high humidity air at room temperature.

4.1 Material Characterization

AISI 4340 is an oil hardening Ni-Cr-Mo steel recommended for many high strength applications because of its highly desirable combination of high strength, toughness, and ductility.

The material for this program was procured as 1" x 4¼" x 72" (.025 x .108 x 1.829 mm) long bars in the forged and annealed condition. The chemical composition of this material was reported to us as follows:

Carbon	0.40%
Manganese	0.77
Silicon	0.32
Sulfur	.004
Phosphorus	0.009
Chromium	0.75
Nickel	1.68
Molybdenum	0.24
Copper	0.09

The heat treatment used to bring the specimen coupons to the 280 ksi level is as follows:

Austenite	1500°F	Oil Quench/125-150°F
Temper	400°F	2 Hours

This treatment resulted in a hardness level of 52-54 R_C.

The microstructure of the material in this condition is shown below and consists of fine tempered martensite.

4340, Q+T(52 Rc)

Nital Etch 1000X

Four subsize material verification tensile specimens were prepared from the heat treated material and tested at room temperature. Results were as follows:

Specimen Number	U. T. S. (ksi)	U. T. S. MPa	.2% Y. S. (ksi)	.2% Y. S. MPa	R. A. %	El. %
12-1	301.9	2081.5	202.5	1396.2	51.5	12.8
12-2	303.6	2093.3	202.5	1396.2	47.1	12.1
15-1	294.6	2031.2	205.0	1413.4	52.9	12.3
15-2	301.1	2076.0	201.1	1386.5	52.2	12.5

4.2 Specimen Manufacturing

The specimen material, 4340 vacuum melt MIL-S-8844, was forged to a size of 1" x 4¼" x 72" (.025 x .108 x 1.829 mm). This forging was cut into four 18" (457 mm) pieces. These pieces were then split in half to yield eight specimen blanks for each forging.

The specimen blanks were then milled to a slight oversize condition. A minimum of .100 in. (2.54 mm) of material was removed from the forged surface.

The coupons were then contoured to the specimen configuration and were ready for heat treat. The specimens were heat treated to the 260-280 ksi ultimate strength level. After heat treat, the specimens were Blanchard ground removing approximately .075 in. (1.9 mm) from the faces of the specimens. The final .020 in. (.5 mm) on all surfaces was removed by the low stress grinding conditions given in Table I. A sketch of the specimen used for tensile and fatigue tests is shown in Figure 2. The stress corrosion specimen is shown in Figure 3.

After grinding the edges of the gage area were radiused and polished in the longitudinal direction.

The specimens were now complete and ready for baseline testing.

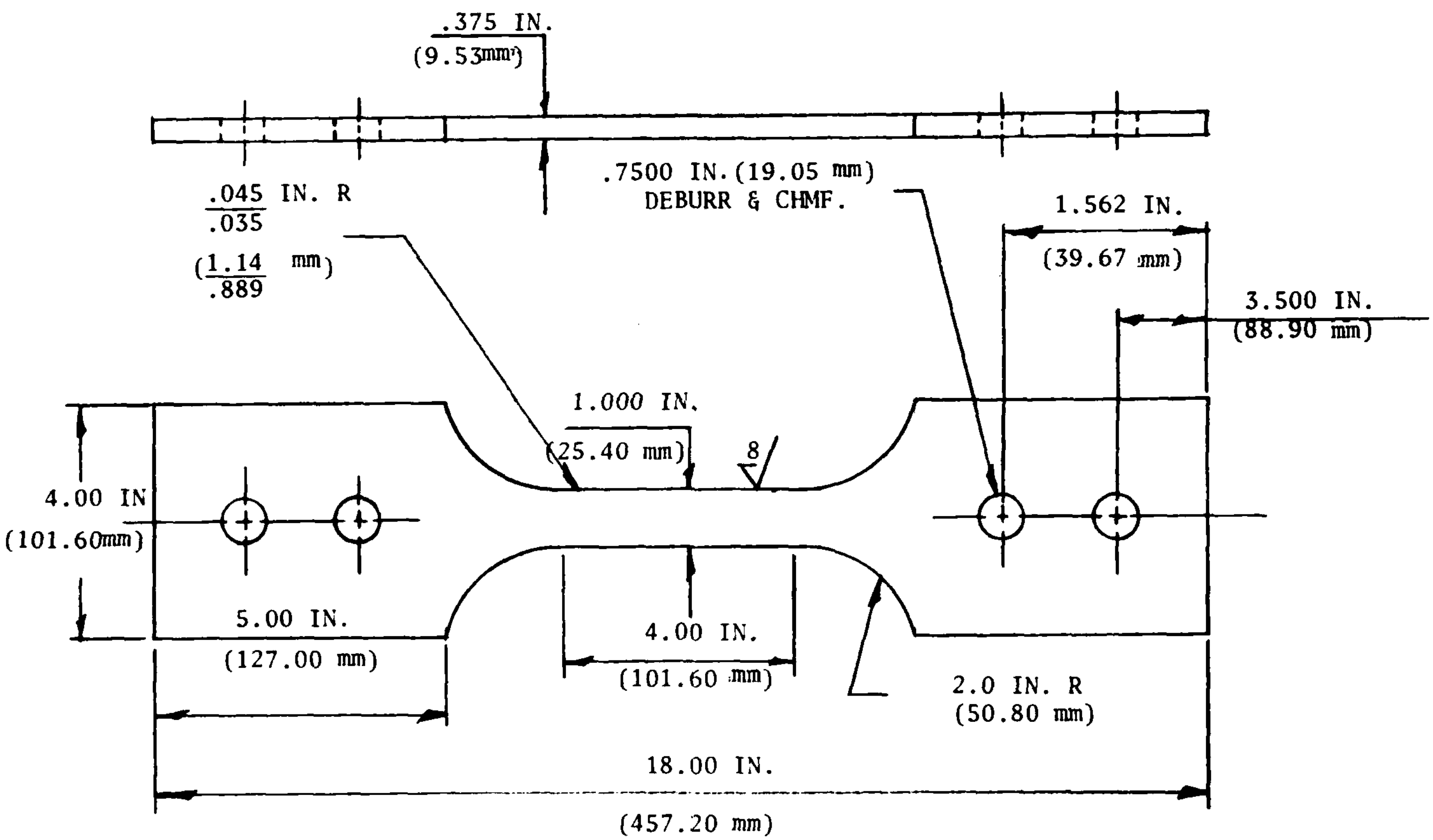


Figure 2 - Tensile and Fatigue Test Specimen

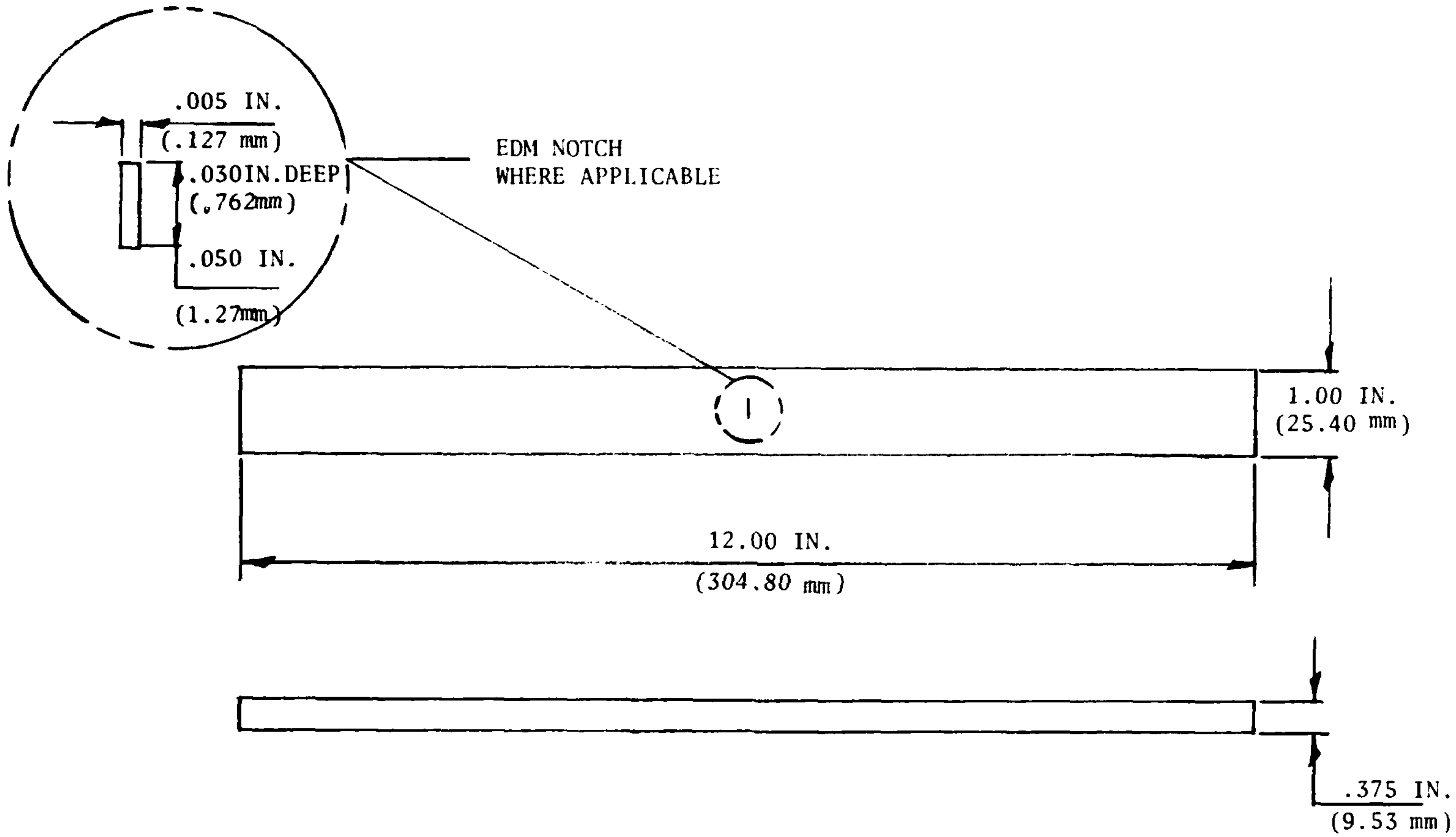


Figure 3 - Stress Corrosion Test Specimen

4.3 Shot Peening

The shot peening for each of the five cycles was performed at the Metal Improvements Company, Blue Ash, OH. The parameters called out in MIL-S-13165B were used throughout the program.

The specimens were clamped in a vertical position and rotated at a speed of 10-15 rpm. Six nozzles were used to propel the shot at the specimen. These nozzles oscillated during peening to ensure consistent overall coverage. After peening for three minutes the specimen was flipped end for end in the holding fixture and peened for an additional three minutes.

The peening parameters used throughout the program were as follows:

Shot Type	=	Hard Steel
Shot Size	=	230
Coverage	=	200%
Intensity *	=	.008 to .012A (.2 to .3 mm A)

* The high intensity metallography specimens had an intensity of .012 to .016A (.3 to .4 mm A).

4.4 Cadmium Plating

The cadmium plating for each of the five cycles was performed at the Hohman Plating Company in Dayton, OH.

The procedure used was in accordance with MIL-C-8837, Type II. The specification is a vacuum deposition process with a supplementary chromate treatment.

The specimens were lightly dry blasted just prior to insertion in the vacuum chamber. This blasting or cleaning process does not produce a rougher surface than that called out on the specimen drawing.

Immediately after plating, the specimens received the chromate treatment to form a protective film.

5.1 Metallography of Shot Peened and Cadmium Plated Surfaces

The metallographic specimens prepared for this program were oriented parallel and perpendicular with respect to the machining lay. The specimens were mounted in epoxy material embedded with aluminum oxide pellets for optimum edge retention. They were polished by conventional means and examined in the unetched and etched conditions at magnifications of up to approximately 1000X. The etchant used was a 2% Nital solution.

Baseline 4340 samples and five groups of samples with varying number of peening cycles and intensities were examined. Surface structural features are briefly described and characterized by photomicrographs shown in Figures 4 through 9.

Traces of thin white layer were observed on the surface of the peened samples. These white or light etching layers and stringers may be attributable to a high degree of surface plastic deformation. The thin layers probably represent highly deformed "amorphous" material rather than untempered martensite which has a similar appearance.

1000X
Nital Etch
Mt. 23623

Baseline 4340

The surface exhibited slight roughness with small isolated areas of disturbed material. This disturbance took the form of fractured slivers of metal and detached debris.

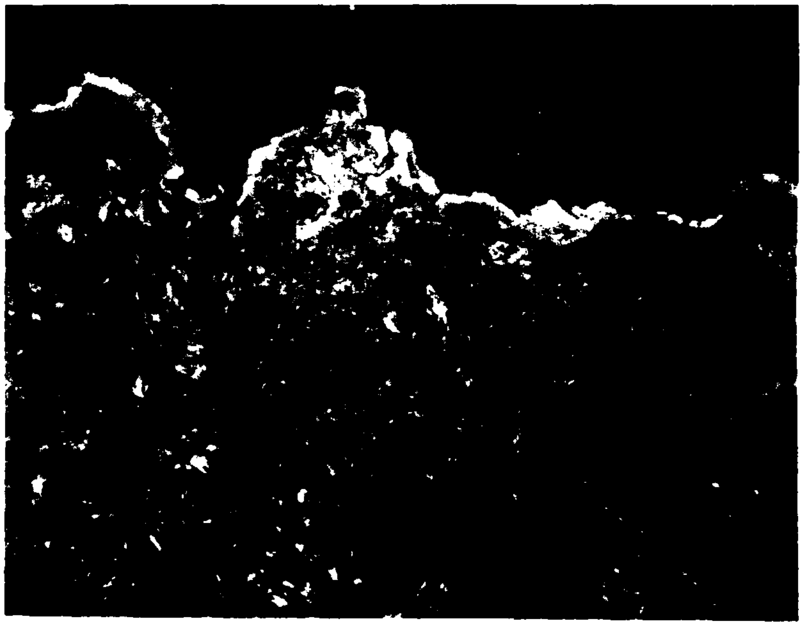
Figure 4 - Photomicrograph of typical test surface - Baseline 4340

1000X
Nital Etch
Mt. 23693

Cycle I

The surface of these samples exhibited slight roughness and instances of a thin deformed white layer. No significant difference in surface topography or texture was noted between the low and high intensity samples of this group.

Figure 5 - Photomicrograph of typical test surface
Cycle I



1000X
Nital Etch
Mt. 23862

Cycle 2

The surfaces of these samples exhibited greater roughness than those of Cycle 1. The surfaces contained instances of slivers, laps, microcracks, and light etching areas of highly worked material. The photomicrograph depicts one of the more severe areas of disturbance.

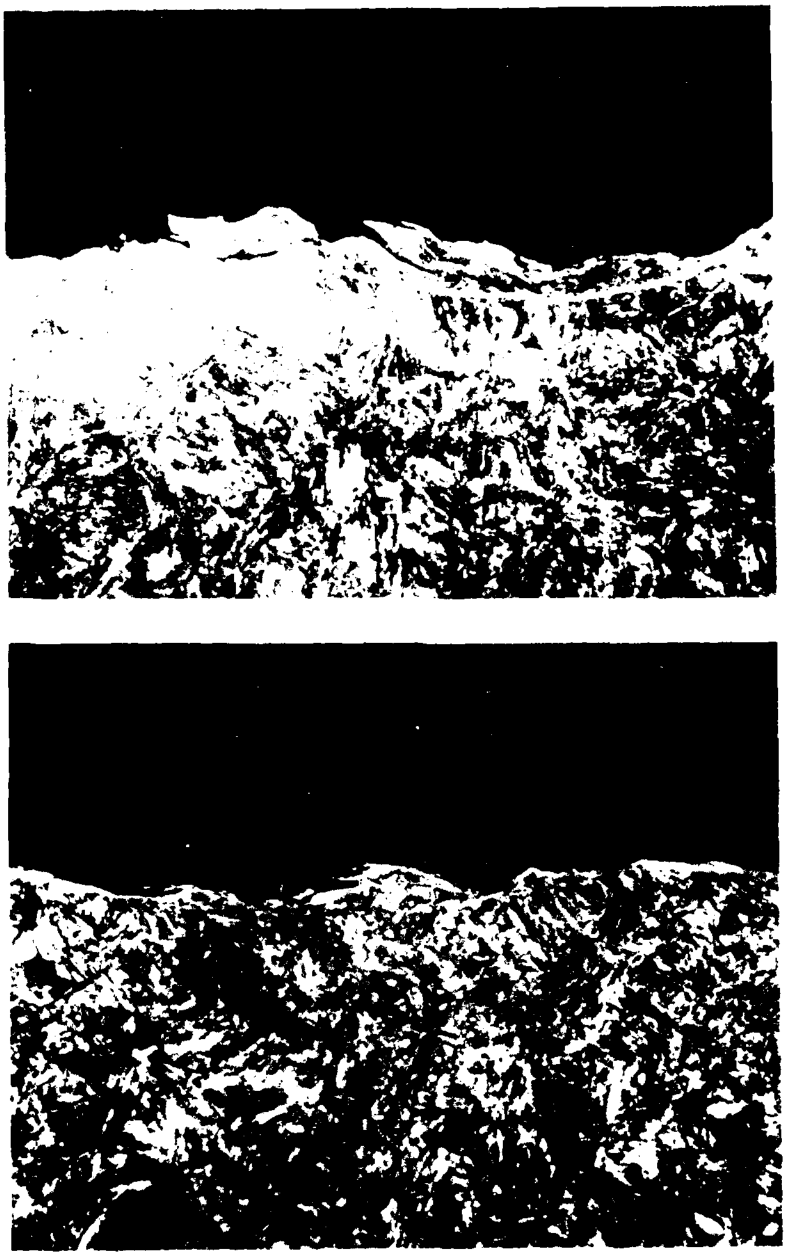
Figure 6 - Photomicrograph of typical test surface - Cycle 2

1000X
Nital Etch
Mt. 23923

Cycle 3

The surfaces contained isolated laps, folds, fragmented slivers and light etching areas of highly worked material. One of the more severe areas of disturbance is characterized in the photomicrograph.

Figure 7 - Photomicrograph of typical test surface - Cycle 3



1000X
Nital Etch
Mts. 23993, 23994

Cycle 4

Surface laps, microcracks, slivers, raised areas of deformed and fragmented material, and areas of white layer were observed.

Figure 8 - Photomicrograph of typical test surface - Cycle 4

1000X
Nital Etch
Mt. 24022

Cycle 5

Thin slivers, laps, areas of fragmented material and white layer were observed.

Figure 9 - Photomicrograph of typical test surface - Cycle 5

5.2 Analysis of Test Failures

In addition to the preceding general characterization of surface features, metallographic studies were performed on failed test specimens in an attempt to ascertain the character of the surface at the failure initiating site. The particular surface alteration of concern was presence of a white layer. The specimens selected for this cursory study represented parent or baseline material and extremes in test life for various fatigue and stress corrosion test conditions. These specimens are identified as follows:

Specimen Number	Surface Condition	Test Conditions
71 (Fatigue)	Cycle 1	170 ksi
31 (Fatigue)	Cycle 5	170 ksi
48 (Fatigue)	Parent	200 ksi; R = 0.1
76 (Fatigue)	Cycle 2	200 ksi; R = 0.1
7 (Fatigue)	Cycle 5	200 ksi; R = 0.1
93 (Fatigue)	Parent	200 ksi; R = -0.3
52 (Fatigue)	Cycle 4	200 ksi; R = -0.3
10 (Stress Corrosion)	Parent	240 ksi, Precrack
8 (Stress Corrosion)	Cycle 1	240 ksi, Precrack
5 (Stress Corrosion)	Cycle 3	240 ksi, Precrack
1 (Stress Corrosion)	Cycle 4	240 ksi, Precrack
2 (Stress Corrosion)	Cycle 5	240 ksi, Precrack
4 (Stress Corrosion)	Cycle 5	240 ksi, Precrack

Before proceeding with metallographic examination of the test specimens, a test blank and the two parent specimens, No. 48 and No. 93, were etched for presence of any significant grinding burn. This was performed in order to resolve the issue of whether the presence of white layer could also be traceable to machining in the manufacture of the specimens. The three specimens were etched using a multi-step procedure widely used in industry which consisted of a dilute solution of 4% nitric acid in water and a solution of 2.5% hydrochloric acid in acetone. One of the parent specimens was also etched with a 2% nital solution. Neither of these etching techniques revealed presence of grinding burn on the specimens.

The test specimens were first examined on a binocular microscope at magnifications of up to approximately 40X in order to locate failure origin. The examination of the fatigue specimens revealed that origins of failure were located at either one of the corners of the specimen or on the sides (or thickness) of the specimen. The failure in the stress corrosion specimens initiated from the pre-existing fatigue crack that was introduced at the bottom of the EDM notch.

Fatigue specimens exhibiting corner failures were metallographically viewed in two orientations - one a longitudinal view through the area of origin (View A) and the other a transverse view of the corner in question (View B). Other initiation sites on fatigue and stress corrosion specimens were examined by a longitudinal section which intersected the area of the origin. The sketch in Figure 10 provides further clarification of the manner in which the metallographic specimens were prepared.

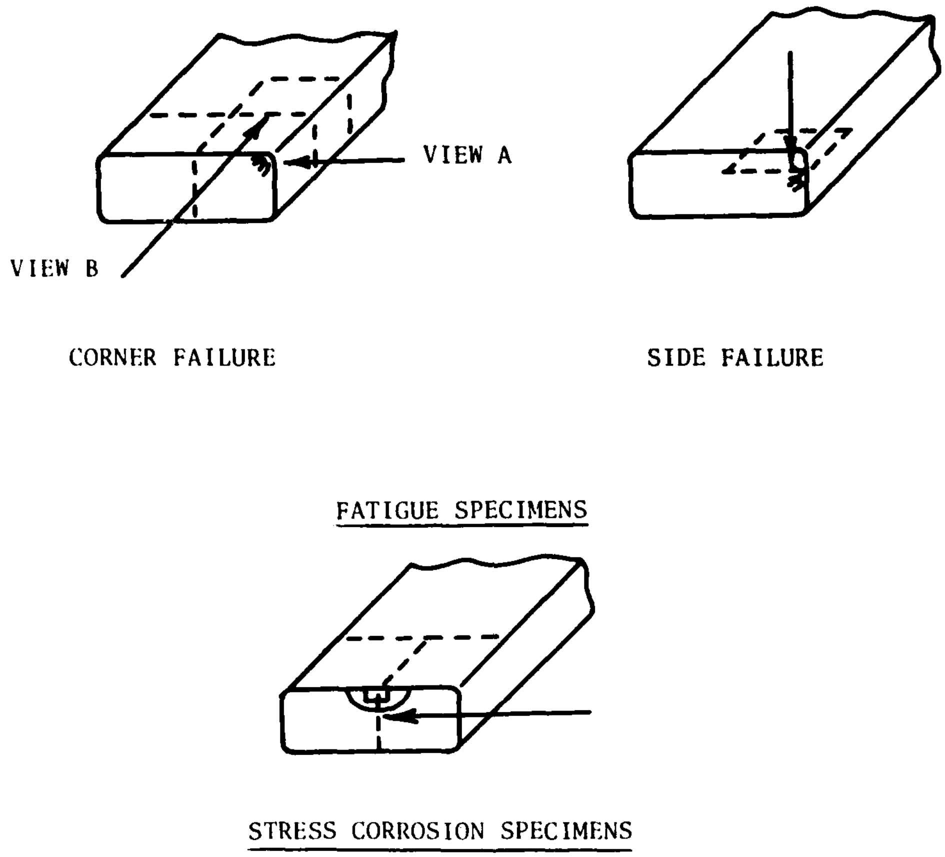


Figure 10 - Sketch illustrating orientation of metallographic specimens. Dotted lines represent cut lines. Arrow denotes direction of microscopic viewing

The metallographic specimens were ground and polished to approximately the center of the initiation site and examined in the unetched and etched conditions at magnifications up to approximately 1200X. Findings are summarized in the table below:

Specimen Number	Failure Location	Surface Features
71; Cycle 1	Corner	At origin area: white deformed layer. Corner cross section: thin discontinuous white layer, instances of deformed metal, slivers and microcracks.
31; Cycle 5	Corner	At origin area: microcracks; deformed layer. Corner cross section: similar features as above but more severe overall.
48; Parent	Side	At origin area: no damage, but few isolated instances of light etching deformed layer and slivers were noted on the surface away from origin.
76; Cycle 2	Corner	At origin area: no obvious damage. Corner cross section: few isolated slivers and deformed scallops.
7; Cycle 5	Side	At origin area: thin white layer; incipient fatigue crack associated with scallops of deformed metal, white layer and laps.
93; Parent	Side	At origin area: no damage; but isolated instances of light etching deformed metal and microcracks were observed away from origin.
52; Cycle 4	Corner	At origin area: thin white layer and sliver. Corner cross section: isolated scallops of deformed metal, white layer, laps and slivers
SC Specimens No's. 1,2,4,5, 8, 19	Fatigue Precrack	At origin area: no apparent alterations from peening cycles.

This brief metallographic study indicates that white layer was not associated exclusively with the initiative area of specimens exhibiting the lowest fatigue life. Fatigue initiation was also influenced by apparently other forms of surface degradation, such as microcrack and slivers, and by specimen geometry (i.e., the corner areas).

It should be clarified that the fatigue origins, particularly the corner failures, had a finite dimension and did not exist as a single point source. For this reason, the nature of the exact alteration that may have initiated the fatigue crack can be in doubt particularly since the alterations on a given surface were intermittent, minute, and of various forms. Scanning electron microscopy (SEM) coupled with a microsectioning technique could be implemented as a more sophisticated phase of study.

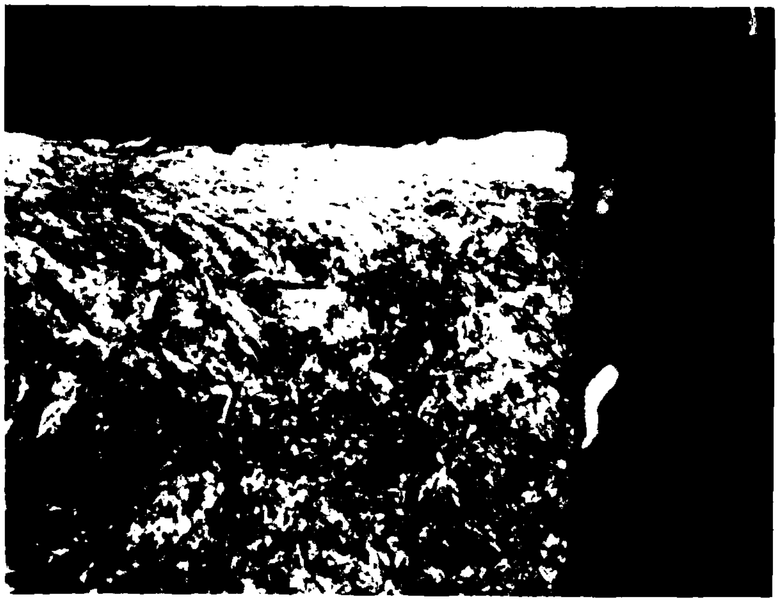


Figure 11 - Microstructural features observed on fatigue Specimen 71 (Cycle 1)

Top: Surface alterations at origin areas (View A)
Bottom: Surface alterations at corner (View B)

Etchant: Nital

MAG 1000X

Figure 12 - Microstructural features observed on fatigue Specimen 31 (Cycle 5)

Top: Surface alterations at origin area (View A)
Bottom: Surface alterations at corner (View B)

Etchant: Nital MAG 1000X

5.3 Tensile and Fatigue

All tensile and fatigue tests were conducted on a 130 kip (896 MPa) Servo controlled closed loop hydraulic test stand (Figure 13). The primary load cell and all support equipment were calibrated against standards traceable to the Bureau of Standards before and after this test series. The test fixture and loading grips were aligned using a strain gaged calibration specimen shown in Figure 14.

The tensile tests were run in dry laboratory air at 68/78° F (20/25°C) in accordance with ASTM E-8. A strain rate of .005 in./in./min. (.127 mm/mm/min.) to failure was used for all tests. Stress/strain recordings were developed with a 1.00" (25.4 mm) gage length extensometer attached directly on the test specimens. All data from this test series are shown in Table II and plotted in Figure 15. The graphs in Figure 15 show that there was no degradation in tensile properties (ultimate, 2% yield, elongation) as a result of the multiple shot peening/cadmium plating cycles.

The fatigue tests were conducted in the constant load axial mode at an "R" ratio of 0.1 and -0.3. The test environment was high humidity air exposure on the test surface. This was accomplished by passing compressed laboratory air through a column of water to a plastic jacket surrounding the test specimen gage sections. No pre-conditioning was performed prior to testing. A sinusoidal wave loading rate was used for all tests at a frequency of 2 to 4 Hz.

Data from the fatigue test series are shown in Table III and plotted as bar graphs in Figures 16 to 19.

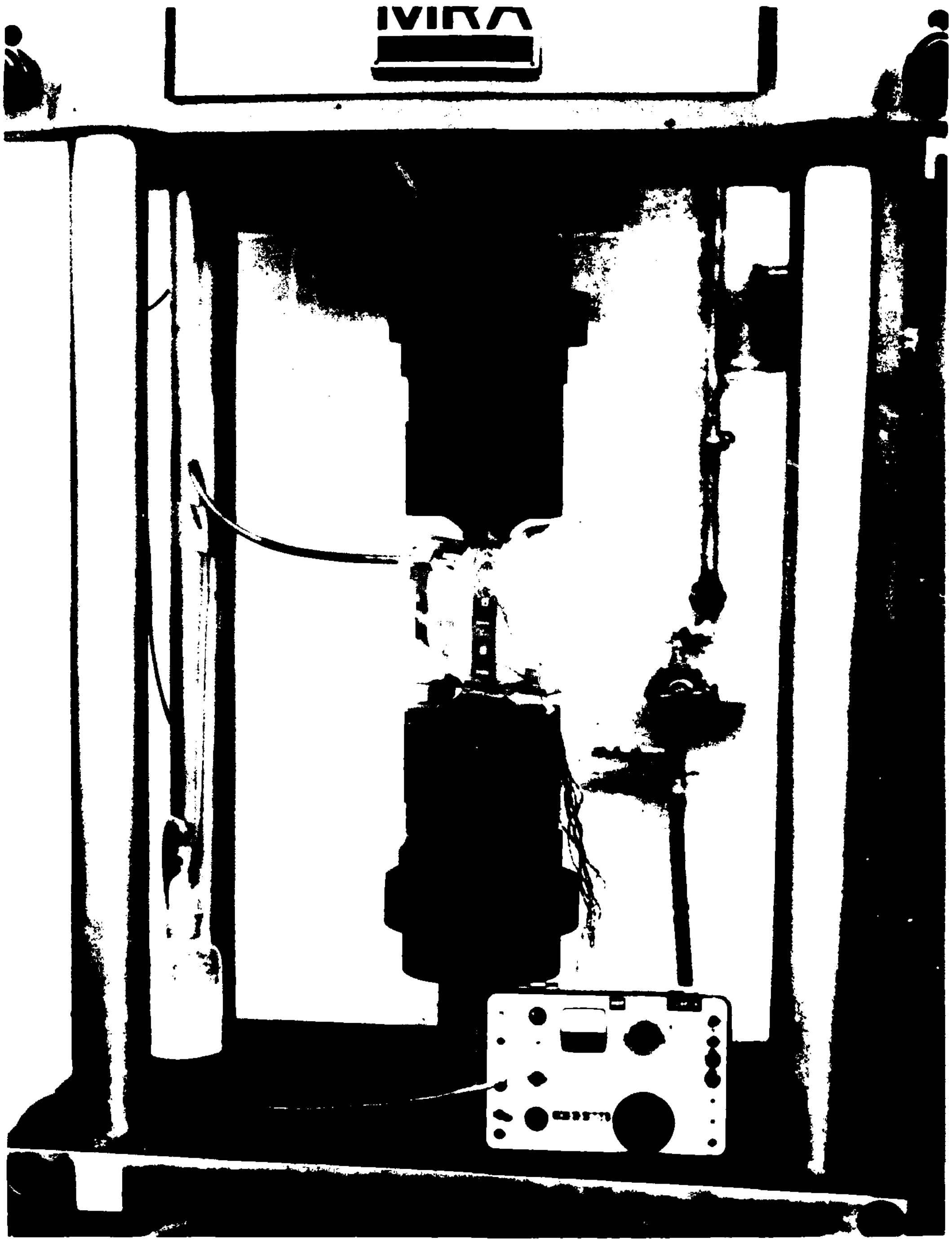


Figure 13 - Closed Loop Hydraulic Test Stand

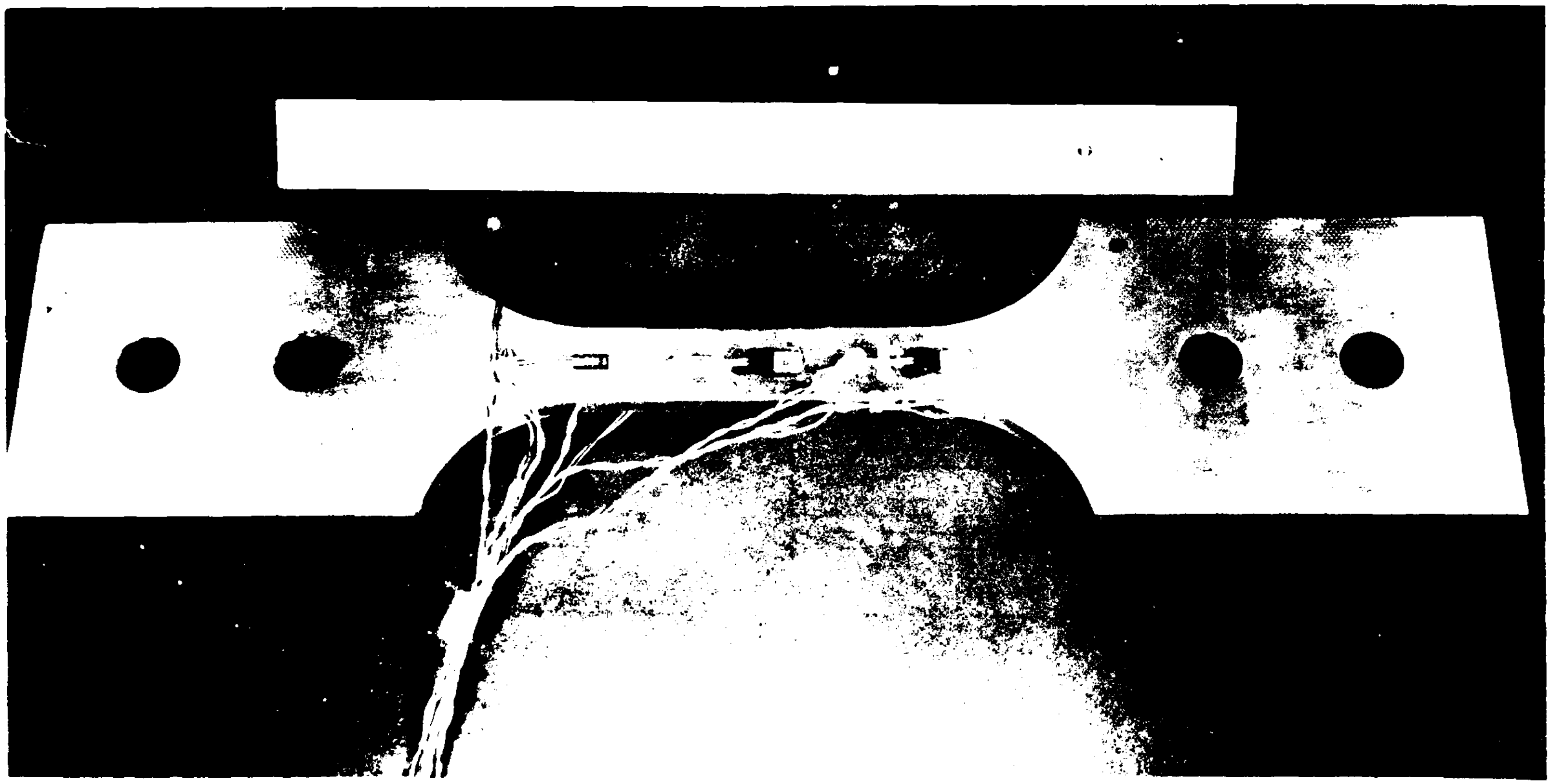


Figure 14 - Calibration Specimen

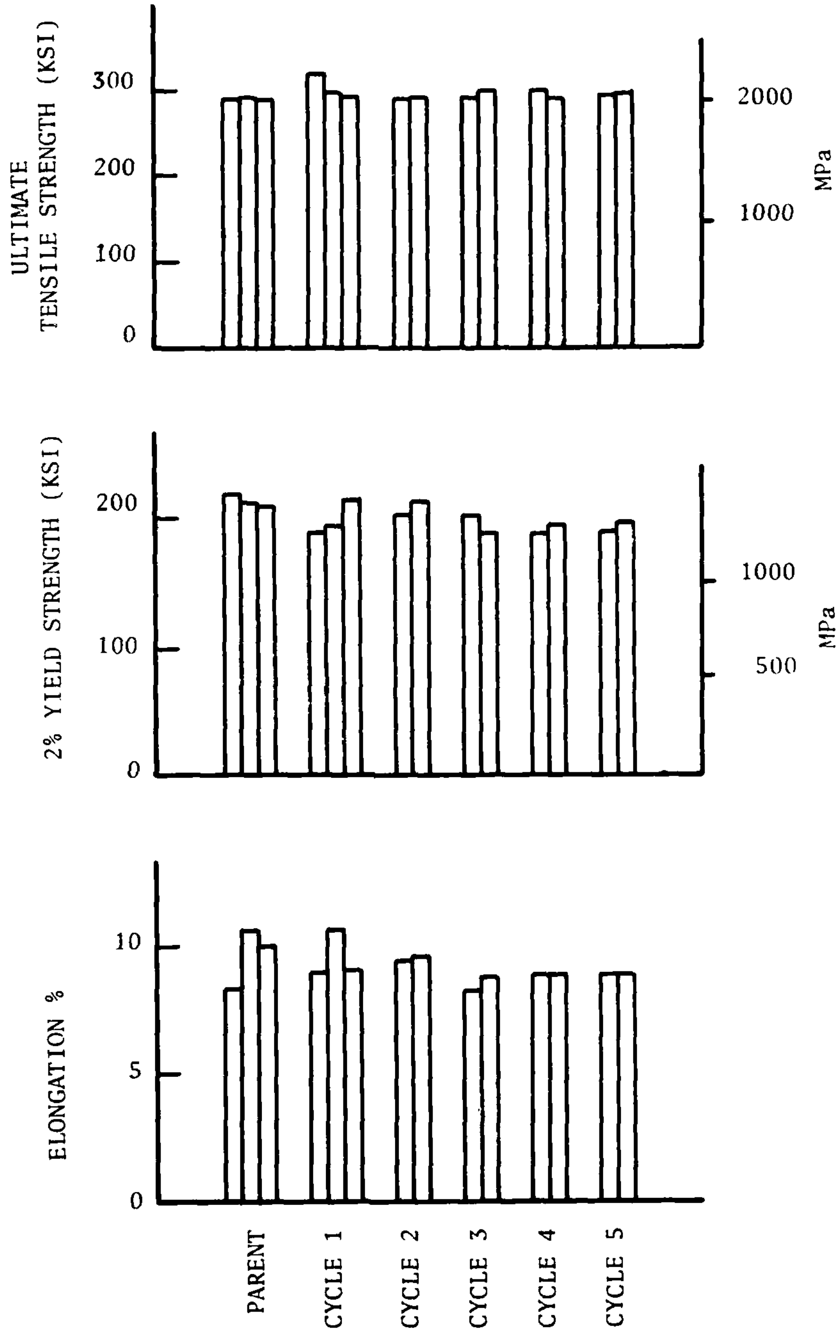


Figure 15 - Tensile Properties Results

	Test Stress	R Ratio
Figure 16	170 ksi	+0.1
Figure 17	170 ksi	-0.3
Figure 18	200 ksi	+0.1
Figure 19	200 ksi	-0.3

The limited number of test points makes it difficult to establish specific conclusions. However, at each of the four test levels, an increase in cycles to failure was evident in the first and second peening and cadmium plating cycles.

A slight degradation in cycles to failure is apparent in the fourth and fifth peening and cadmium plating cycles but this degradation level still exceeds the lives established in the testing of the Cycle 1 specimens.

Figures 18 and 19 also include test pointsfor specimens that were cycled in fatigue between successive peening and cadmium plating cycles.

The average life of the Cycle 1 specimens was used as a basis. The quarter life value was used as the number of cycles the specimens would undergo between each peening and cadmium plating cycle.

As can be seen in Figures 18 and 19, this interrupted cycling caused no degradation in the cycles to failure.

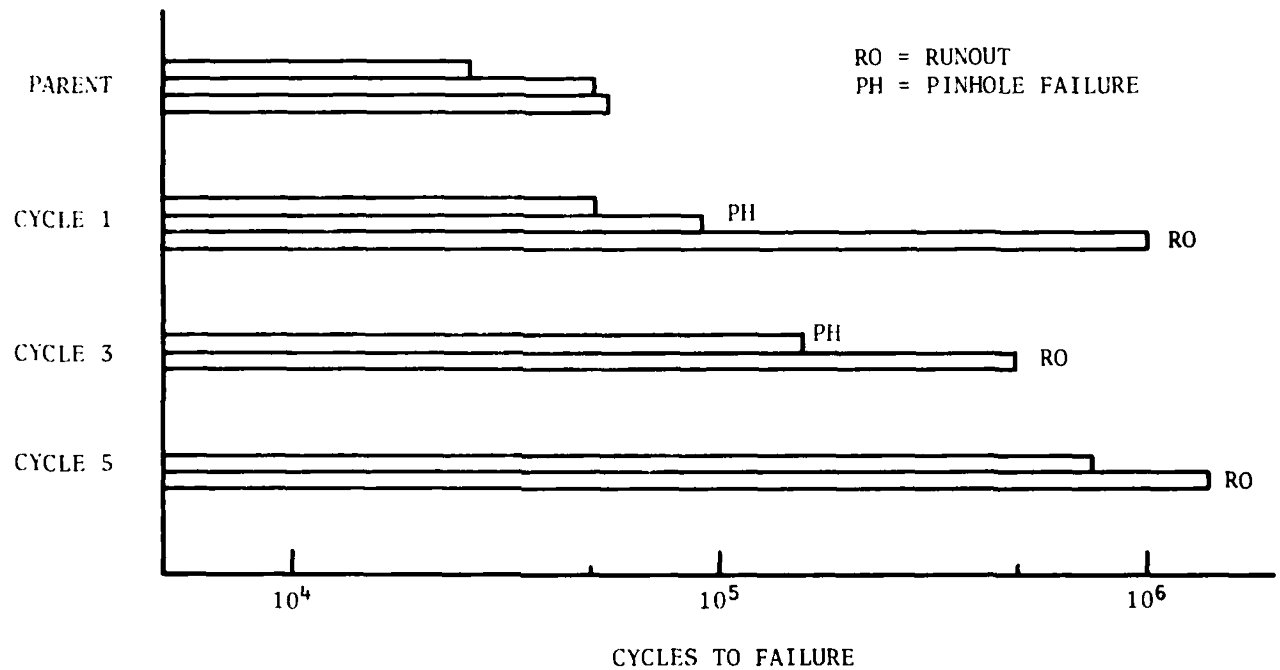


Figure 16 - Fatigue test data, 170 ksi test stress and +0.1 R ratio

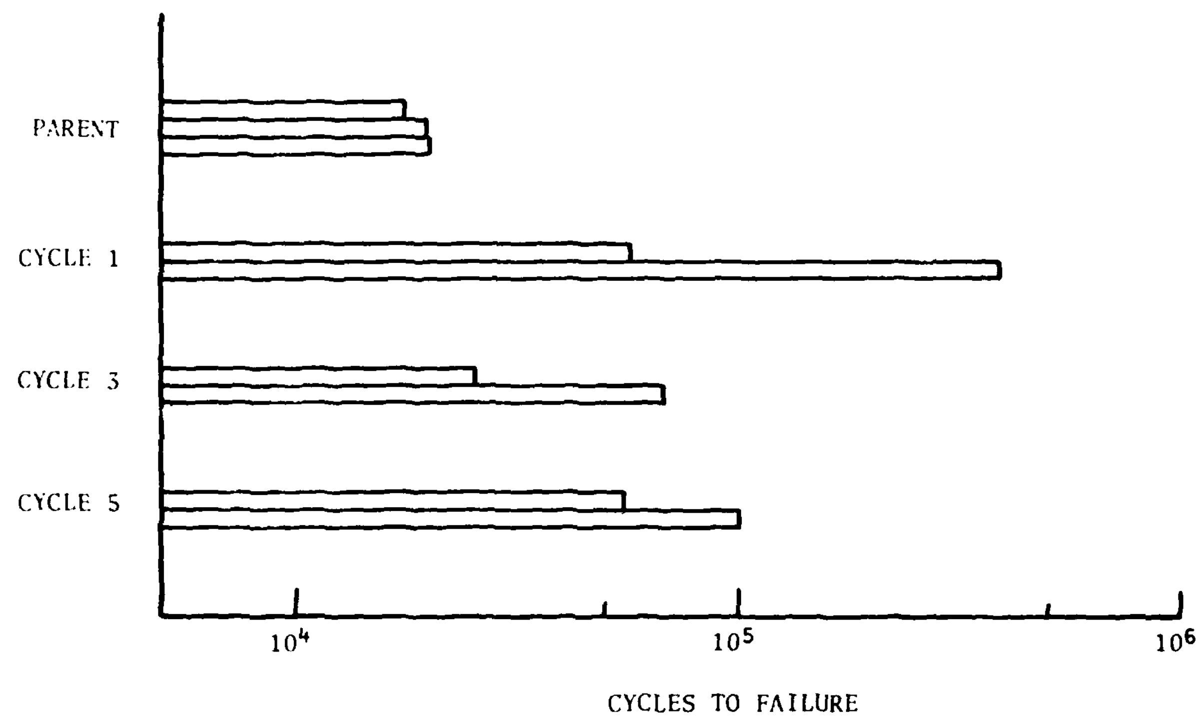


Figure 17 - Fatigue test data, 170 ksi test stress and -0.3 R ratio

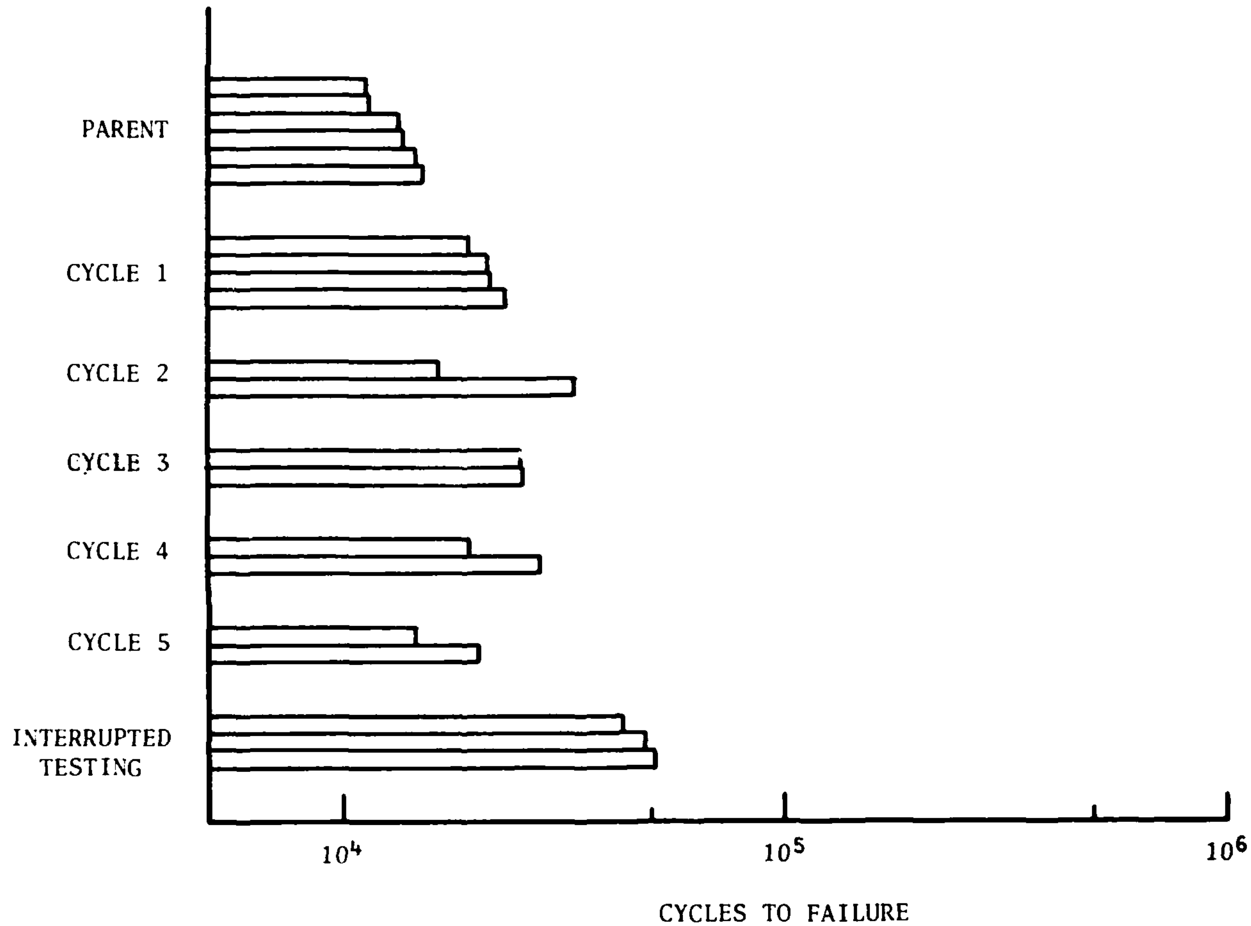


Figure 18 - Fatigue test data using 200 ksi test stress and +0.1 R ratio

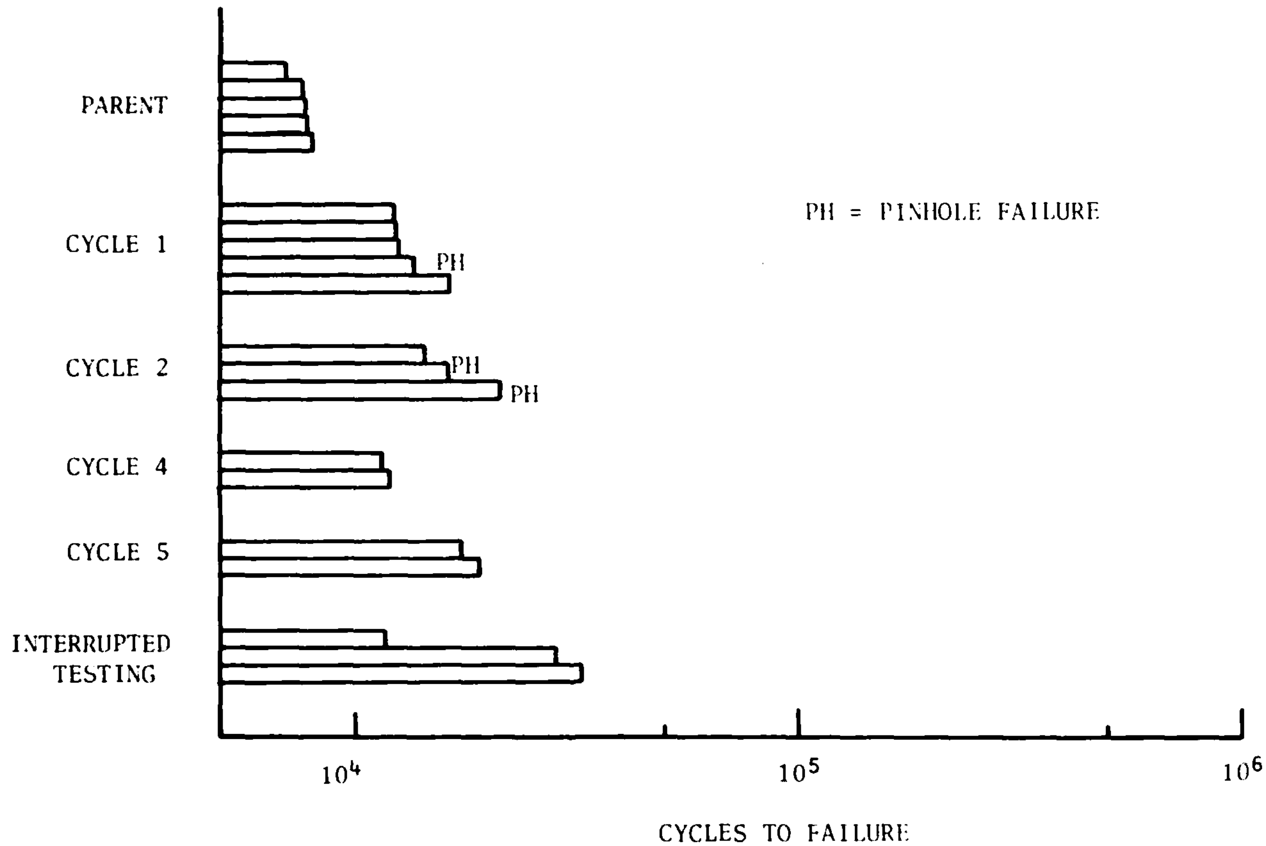


Figure 19 - Fatigue test data, 200 ksi test stress and -0.3 R ratio

5.4 Stress Corrosion Tests

Stress corrosion testing was conducted per ASTM G39-73, "Standard Method for Preparation and Use of Bent-Beam Stress-Corrosion Specimens" with one exception. Test were conducted via a constant load, four-point bending technique rather than the constant displacement, four-point bending procedure outlined in the ASTM method. Specimens were nominally 3/8 in. thick by 1 in. wide by 12 in. long (9.5 x 15.4 x 305 mm). Loading fixtures were constructed such that the distance between end supports was 11 in. (279.4 mm) and the bending moment arm was 4 in. (101.6 mm). Therefore the constant bending moment test section of the specimen was the central 3 in. (76.2 mm) of its length. A schematic diagram of the loading fixture is shown in Figure 20. The loading fixture was mounted on a creep-rupture testing machine such that the dead-weight load could be applied using the 20:1 mechanical advantage of the equipment's lever system. Three such testing machines were outfitted and employed for testing in this program. A photograph of a test machine with specimen and loading fixture in place in shown in Figure 21.

The test environment was air at 80-100% relative humidity. This atmosphere was produced by bubbling compressed air through tap water and passing it into a plastic bag surrounding the test section.

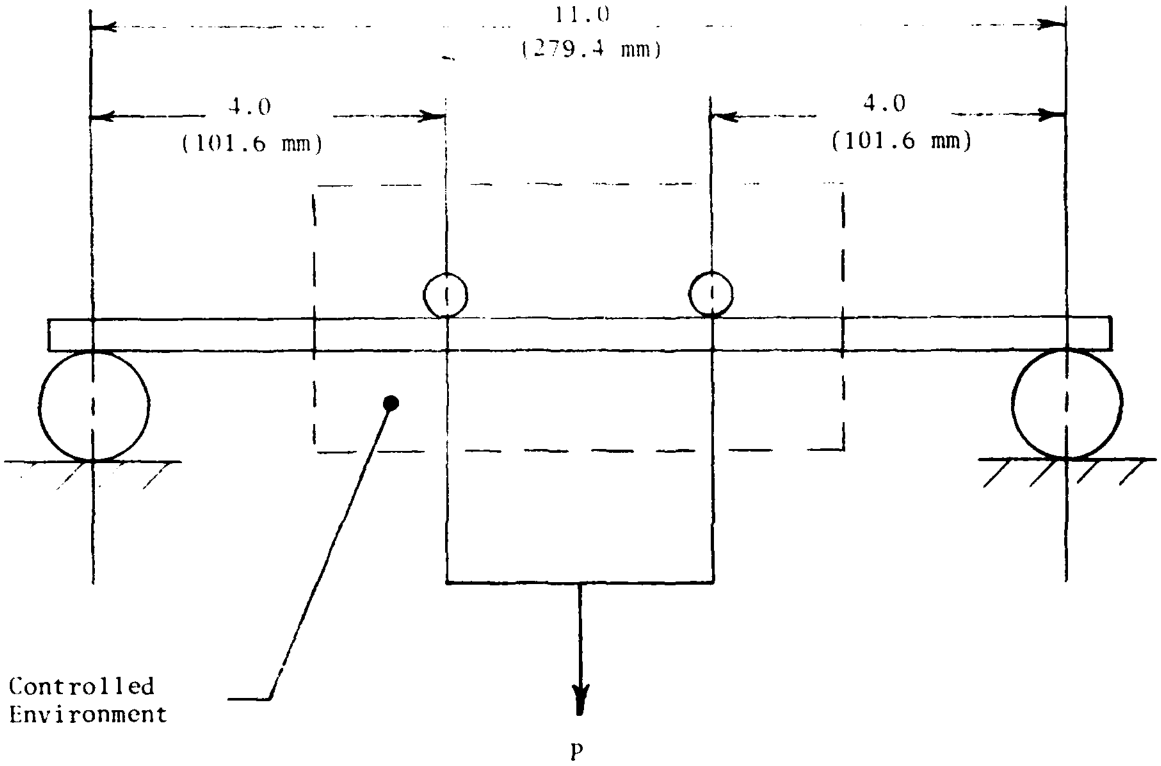


Figure 20 - Fixture Schematic

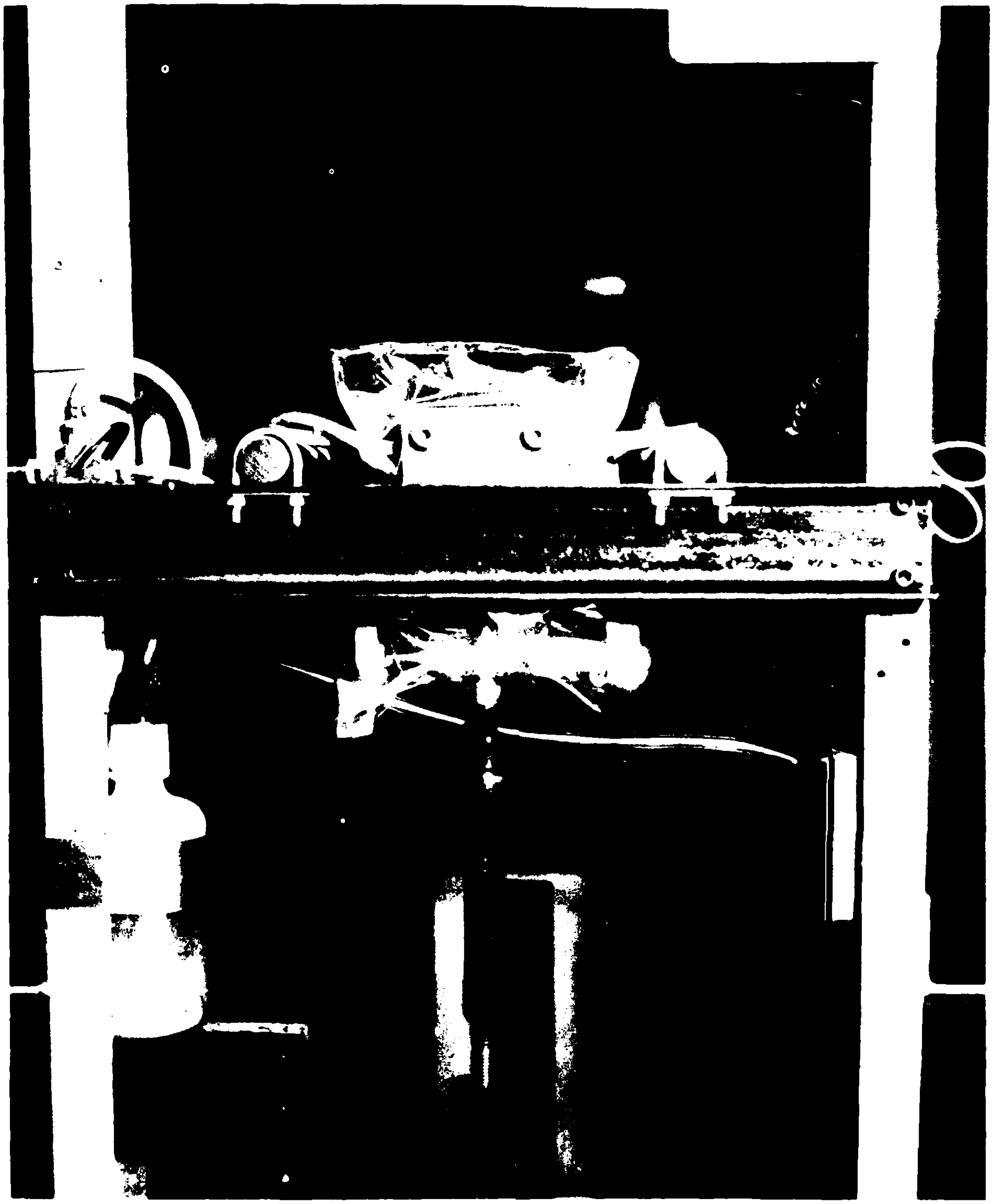


Figure 21 - Stress Corrosion Test Stand

A total of twenty-four stress corrosion tests were performed, fourteen on smooth specimens and ten on fatigue precracked specimens. The latter ten specimens were fatigue cracked following their manufacture but prior to any shot peening plus plating plus stripping cycles. All multiple shot peening plus plating plus stripping cycles were performed on individual specimens prior to stress corrosion testing. Each specimen was rinsed in acetone and air dried immediately prior to testing.

The ten fatigue precracked specimens were manufactured with a 0.05 in. wide by .025 in. deep (1.27 x .635 mm) notch produced by electrical discharge machining. The notch was located on one specimen face at the specimen mid-length and was symmetric with respect to the one inch specimen width. Fatigue precracking was performed in room temperature ambient air under three-point bend loading at a stress ratio, A, of 0.9 and a cyclic frequency of 30 Hz. Fatigue cracks were initiated at a nominal maximum surface stress of 100 ksi (689.5 MPa) and were allowed to propagate at the same nominal stress level until the surface notch plus crack length reached 0.10 in. (2.54 mm). All precracking was performed prior to shot peening plus plating plus stripping cycles.

Stress levels for stress corrosion testing were selected by the AFML contract monitor. Initially, the stress level was chosen to be equal to the 0.2% offset yield stress for the material. This level subsequently was increased after discussions with the AFML contract monitor when no specimen failures were observed at the lower stress level. Therefore, the surface stress level, as reported herein is a pseudo-elastic rather than an actual stress level which is indeterminate.

The load level for each test was calculated from the selected stress level using the simple beam formula, $\frac{MC}{I}$, where:

M = bending moment

C = half thickness of beam

I = moment of inertia

After loading, the specimen was held at constant load in the moist air environment for at least 200 hours or until fracture whichever occurred first. Results of all stress corrosion tests are presented in Tables IV and V.

After testing (200 hours moist air environment), the specimens were visually examined for traces of corrosion. There were no signs of corrosion on any of the tested specimens.

SECTION VI

CONCLUSION

This program has examined the effect on fatigue and stress corrosion resistance of multiple shot peening/cadmium plating cycles similar to those used in the overhaul facilities of aircraft landing gear.

Conclusions based on the range of parameters studied are as follows:

1. No detrimental effects were observed when repeated shot peening/cadmium plating cycles were performed on a monoblock test specimen. The maximum number of peening/plating cycles investigated was five.

2. The fatigue behavior appears to have been enhanced when multiple shot peening cycles were applied on the specimens. This enhancement was most noticeable in the first three cycles.

3. Significant metallurgical phase differences were not observed between multiple peening/plating cycles. White stringers at the surface tended to become more prominent in the later cycles. These stringers are considered to be an etching phenomenon related to the extreme level of plastic deformation in the peened surfaces and not significant to properties.

4. Stress corrosion testing was inconclusive as to benefits or detrimental effects of the shot peening/cadmium plating as all smooth test specimens exceeded the 200 hour limit as called out in the test procedure. Precrack specimens failed short of the 200 hour limit in the 4th and 5th cycles. The failure was subsurface (about .100 in. under surface) and not attributed to surface effects or white stringers.

TABLE 1

LOW STRESS GRINDING CONDITIONS USED FOR TEST SPECIMEN MANUFACTURING

Grinding Wheel	=	A60HV	
Wheel Speed	=	3000 ft./min.	(914.4 m/min.)
Downfeed		16 passes at .0005 in./pass	(.010 mm/pass)
		2 passes at .0004 in./pass	(.010 mm/pass)
		6 passes at .0002 in./pass	(.005 mm/pass)
Crossfeed	=	.100 in./pass	(2.54 mm/pass)
Table Speed	=	40 ft./min.	(12.2 m/min.)
Depth of Grind	=	.020 inch	(51 mm)
Grinding Fluid	=	Sulfurized Oil	
Wheel Width	=	1.0 inch	(25.4 mm)

TABLE 2

TENSILE DATA

AISI 4340 Steel

68/70°F
20/25°C

Surface Condition	S/N	U. T. S. Ksi	U. T. S. MPa	.2% Y. S. Ksi	.2% Y. S. MPa	Elong. %
Baseline	12	292.2	2,014.7	216.0	1,489.3	8.5
Parent	15	295.9	2,040.1	211.1	1,456.2	10.6
Metal	67	293.3	2,022.2	207.4	1,430.0	10.1
1 Cycle	64	321.7	2,218.0	189.8	1,308.6	9.2
Shotpeen &	1	297.0	2,047.7	196.6	1,355.5	10.5
Plate	18	295.7	2,038.8	215.4	1,485.1	9.1
2 Cycles	55	294.4	2,029.8	204.3	1,408.6	9.5
Shotpeen & Plate	2	296.0	2,040.9	212.8	1,467.2	9.7
3 Cycles	4	293.9	2,026.4	202.6	1,396.9	8.5
Shotpeen & Plate	69	301.7	2,080.2	187.8	1,294.8	9.0
4 Cycles	16	300.2	2,069.8	188.8	1,301.7	9.0
Shotpeen & Plate	43	294.4	2,029.8	196.8	1,356.9	9.0
5 Cycles	77	297.4	2,050.5	191.0	1,316.9	9.0
Shotpeen & Plate	83	298.9	2,060.9	198.0	1,356.2	9.0

TABLE 3

FATIGUE DATA

AISI 4340 Steel

Specimen Number	Peen/Plate Cycle	R Ratio	Maximum Stress Ksi	Maximum Stress MPa	Cycles to Failure	Notes
73	None	0.1	200	1379	11,460	
8	None	0.1	200	1379	11,660	
48	None	0.1	200	1379	13,550	
30	None	0.1	200	1379	13,870	
65	None	0.1	200	1379	14,910	
51	None	0.1	200	1379	15,140	
54	1	0.1	200	1379	19,550	
47	1	0.1	200	1379	21,600	
63	1	0.1	200	1379	21,730	
11	1	0.1	200	1379	23,710	
56	2	0.1	200	1379	16,650	
76	2	0.1	200	1379	33,560	
70	3	0.1	200	1379	25,380	
58	3	0.1	200	1379	25,890	
35	4	0.1	200	1379	19,280	
10	4	0.1	200	1379	28,000	
7	5	0.1	200	1379	14,660	
33	5	0.1	200	1379	20,200	
20	None	0.1	170	1172	26,140	
74	None	0.1	170	1172	51,470	
28	None	0.1	170	1172	55,880	
34	1	0.1	170	1172	50,860	
13	1	0.1	170	1172	90,030	Pin Hole Failure
86	1	0.1	170	1172	1,004,670	Runout

TABLE 3
(continued)

FATIGUE DATA

AISI 4340 Steel

Specimen Number	Peen/Plate Cycle	R Ratio	Maximum Stress Ksi	Maximum Stress MPa	Cycles to Failure	Notes
5	3	0.1	170	1172	157,260	Pin Hole Failure
29	3	0.1	170	1172	499,430	Failure
46	5	0.1	170	1172	742,160	Failure
79	5	0.1	170	1172	1,427,120	Runout
24	None	0.1	130	896	38,040	
38	None	0.1	130	896	42,540	
6	None	0.1	130	896	52,150	
17	None	0.1	130	896	58,820	
85	None	0.1	130	896	83,040	
59	None	0.1	130	896	83,322	
21	1	0.1	130	896	1,000,000	Runout
44	None	-0.3	200	1379	7,080	
22	None	-0.3	200	1379	7,710	
93	None	-0.3	200	1379	7,880	
9	None	-0.3	200	1379	8,390	
66	None	-0.3	200	1379	10,690	
25	1	-0.3	200	1379	12,370	
36	1	-0.3	200	1379	12,460	
27	1	-0.3	200	1379	12,520	
23	1	-0.3	200	1379	13,850	Pin Hole Failure
53	1	-0.3	200	1379	16,460	
82	2	-0.3	200	1379	16,450	Pin Hole Failure
57	2	-0.3	200	1379	21,250	Pin Hole Failure
95	2	-0.3	200	1379	14,970	

TABLE 3
(continued)

FATIGUE DATA

AISI 4340 Steel

Specimen Number	Peen/Plate Cycle	R Ratio	Maximum Stress Ksi	MPa	Cycles to Failure	Notes
52	4	-0.3	200	1379	11,450	
96	4	-0.3	200	1379	12,000	
81	5	-0.3	200	1379	19,280	
87	5	-0.3	200	1379	17,600	
26	None	-0.3	170	1172	17,730	
37	None	-0.3	170	1172	19,980	
19	None	-0.3	170	1172	20,040	
71	1	-0.3	170	1172	57,640	
61	1	-0.3	170	1172	389,470	
80	3	-0.3	170	1172	68,850	
91	3	-0.3	170	1172	25,570	
31	5	-0.3	170	1172	55,360	
38	5	-0.3	170	1172	100,830	
78	None	-0.3	130	896	60,180	
88	1	-0.3	130	896	1,000,000	Runout

TABLE 3
(continued)

FATIGUE DATA - INTERRUPTED LIFE

AISI 4340 Steel

Specimen Number	Peen/Plate Cycle	R Ratio	Maximum Stress Ksi	Maximum Stress MPa	Cycles to Failure	Notes
39	1	0.1	200	1379	5,410	Runout
	2	0.1	200	1379	5,410	Runout
	3	0.1	200	1379	5,410	Runout
	4	0.1	200	1379	5,410	Runout
	5	0.1	200	1379	21,480	
				Total	43,120	to Failure
42	1	0.1	200	1379	5,410	Runout
	2	0.1	200	1279	5,410	Runout
	3	0.1	200	1379	5,410	Runout
	4	0.1	200	1379	5,410	Runout
	5	0.1	200	1379	27,100	
				Total	48,740	to Failure
33	1	0.1	200	1379	5,410	Runout
	2	0.1	200	1379	5,410	Runout
	3	0.1	200	1379	5,410	Runout
	4	0.1	200	1379	5,410	Runout
	5	0.1	200	1379	29,430	
				Total	51,070	to Failure
50	1	-0.3	200	1379	3,360	Runout
	2	-0.3	200	1379	5,410	Runout
	3	-0.3	200	1379	3,360	Runout
	4	-0.3	200	1379	3,360	Runout
	5	-0.3	200	1379	13,410	
				Total	28,900	to Failure
75	1	-0.3	200	1379	3,360	Runout
	2	-0.3	200	1379	3,360	Runout
	3	-0.3	200	1379	3,360	Runout
	4	-0.3	200	1379	1,750	
				Total	11,830	to Failure
92	1	-0.3	200	1379	3,360	Runout
	2	-0.3	200	1379	3,360	Runout
	3	-0.3	200	1379	3,360	Runout
	4	-0.3	200	1379	3,360	Runout
	5	-0.3	200	1379	19,140	
				Total	32,580	to Failure

TABLE 4

STRESS CORROSION RESULTS - SMOOTH SPECIMENS

Specimen Number	No. of Plate + Strip Cycles	Nominal (Pseudo-elastic) Surface Stress (ksi)	MPa	Test Duration (hrs)	Result (3)
Smooth Surface					
11	None	205	1413	258	N
12	None	205	1413	257	N
13	None	205	1413	279	N
14	None	205	1413	279	N
16	1	205	1413	259	N
23	1	205	1413	259	N
18	2	240	1655	214	N
21	2	240	1655	209	N
19	3	240	1655	209	N
24	3	240	1655	213	N
17	4	240	1655	215	N
22	4	240	1655	215	N
15	5	240	1655	200	N
20	5	240	1655	200	N

(3) Code described on Table 5

TABLE 5

STRESS CORROSION RESULTS - FATIGUE PRECRACKED SPECIMENS

Specimen Number	No. of Plate + Strip Cycles	Nominal (Pseudo-elastic) Surface Stress (ksi)	MPa	Nominal Surface (2) Stress Intensity Factor ksi $(in.)^{\frac{1}{2}}$	MPa $(in.)^{\frac{1}{2}}$	Test Duration (hrs)	Result (3)
Precracked Nominal Crack Length 0.10 in., 2.5 mm							
9	None	205	1413	42	46	266	N
10	None	205	1413	42	46	266	N
9 (1)	None	225	1551	46	50	216	N
10 (1)	None	240	1655	49	54	214	F
7	1	240	1655	49	54	362	N
8	1	240	1655	49	54	350	F
6	2	240	1655	49	54	213	N
3	3	240	1655	49	54	233	N
5	3	240	1655	49	54	204	F
1	4	240	1655	49	54	42	F
2	5	240	1655	49	54	97	F
4	5	240	1655	49	54	2.2	F

NOTES:
(1) Retest of a specimen from a terminated test at a lower stress.
(2) Calculated per Grandt & Sinclair, "Stress Intensity Factors for Surface Cracks In Bending", ASTM STP 513, Part 1, 1971, pp 37-58.
(3) N = No cracking observed (smooth specimens), test terminated.
N = No crack extension observed (precracked specimens), test terminated.
F = Specimen fractured.

*U.S.Government Printing Office: 1980 — 657-084/85